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Effects of lime, ash and nitrogen fertilizers on nematode populations in Scots Pine forest soils

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With 3 figures

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1. Introduction

Several studies have indicated that nematode populations respond to the application of lime and nitrogen fertilizers in field and laboratory experiments. The application of lime and urea increases the numbers of nematodes initially (FRANZ, 1959; BASSUS, 1960, 1967; MARSHALL, 1974 and HEUNGENS, 1981). SOHLENIUS & WASILEWSKA (1984) found a decrease of the nematode numbers after the application of ammonium nitrate in a field experiment. However, in a laboratory experiment BÅÅTH *et. al.* (1978) observed an increase in the numbers of bacterial feeding nematodes in soil amended with ammonium nitrate.

The application of fertilizers may exert both a direct and indirect influence on nematodes. Some dorylaimid nematodes seem to be sensitive to various disturbances (FERRIS & FERRIS, 1974; WASILEWSKA, 1979; SOHLENIUS & WASILEWSKA, 1984). The changes in the nematode populations after liming and nitrogen application are supposed to correlate with the changes in their food supply (BASSUS, 1960, 1967; BÅÅTH *et al.*, 1978 and HEUNGENS, 1981) e.g. microbial populations, but HEUNGENS (1981) could not exlude the effects of certain alkalizing agents on the hatching of eggs.

The aim of this study was to investigate short-term effects of lime, ash and nitrogen fertilizers on nematode populations in coniferous forest soil under field and laboratory conditions. Changes in soil *p*H after the treatments are supposed to be important. In one field experiment, where the samples were taken the same year as the treatment was made, the doses of lime, ash and urea were chosen to produce the same change in the soil *p*H. In the other field experiment, where the samples were taken during the second growing season, the doses of ash and NPK were the same as those used in forest management.

In the first laboratory experiment the doses of lime and birch ash were chosen to produce the same levels of soil *p*H. In the laboratory experiment, equal amounts of N given as urea or ammonium nitrate resulted in different levels of soil *p*H.

2. Material and methods

2.1. Field experiments

2.1.1. Site description

The investigation was done at 2 experimental sites in southern Finland: Tammela (60° 40′ N, 23° 50′ E) and Ruotsinkylä (60° 25′ N, 24° 50′ E). The respective stands were of 50 and 30-year-old Scots pine of the **Calluna**-type. The soil was a podzol with raw humus. The thickness of the humus layer varied between 3 and 5 cm, locally up to 7 cm. The stands were thinned and slash was removed before the treatments.

2.1.2. *Experimental design*

At Tammela 40 m × 40 m test plots were laid out in an area of 2 ha in 1979 for studying the effects of different fertilizers. The plots were randomised for different treatments, 2 replicates for each. In each main plot, a subplot of 10 m × 10 m was reserved for the sampling of soil fauna. Additional plots of 10 m × 10 m were established for fertilization with ash. At Ruotsinkylä a fertilization experiment with a randomized block design with 10 blocks (4 m × 4 m) was laid out in 1980.

Table 1. Treatments in the field experiments.

Treatment code	Tammela	Ruotsinkylä
C	Control	Control
AP	7,000 kg ash × ha^{-1} 44 kg P × ha^{-1} (in apatite)	6,700 kg ash × ha^{-1} 88 kg P × ha^{-1} (in superphosphate)
A	7,000 kg ash × ha^{-1}	
L		4,000 kg $Ca(OH)_2$ × ha^{-1}
UPK	200 kg N × ha^{-1} (in urea) 83 kg K × ha^{-1} (in biotite) 44 kg P × ha^{-1} (in apatite)	
U		460 kg N × ha^{-1} (in urea)

2.1.3. *Fertilizer treatments*

At Tammela the soils were treated at the end of May 1979. At Ruotsinkylä the treatment was performed twice, after a 19 day interval, 13 May and 1 June 1981 (the second treatment after it had rained). Amounts of ferilizers are listed in table 1.

More details of the Ruotsinkylä and Tammela study sites are given by HUHTA (1984).

2.2. Laboratory experiment

2.2.1. *Experimental design*

Six intact soil blocks (the organic layer including vegetation) were taken from the study site at Ruotsinkylä, and into 6 plastic boxes measuring 40 cm ×60 cm, 11 cm deep. Before insertion, 1 cm of mineral soil was taken from immediately under each plot and spread on the bottom of the box.

Twenty four holes, diameter 4 cm, were bored into each block for the insertion of 8 replicates of each of the 3 test materials.

2.2.2. *Fertilizer treatments*

Organic soil from the same site was brought into the laboratory and sifted through a 10 mm mesh. The minerals to be tested were mixed thoroughly with this soil. Equal portions of these test materials (soil with or without minerals) were weighed and placed into baskets made of plastic mesh (diameter 4 cm, height 8 cm, mesh 1.5 mm) and inserted in the holes in the boxes. At the beginning, the samples totalled about 100 cm^3 in volume and weighed 33 g (sample unit). The test materials were:

Experiment with lime and ash

C: Control, no addition.

AP: 9.7 g (d.m.) of birch ashes and 1.4 g of superphosphate kg^{-1} (f.m.) of soil, equivalent to 1,750 kg ashes and 22 kg P×ha^{-1}

L: 9.7 g (d.m.) $Ca(OH)_2$×kg^{-1}

Experiment with urea and ammonium nitrate

C: Control, mixed soil with no addition.
U: Urea, 2.6 $g \times kg^{-1}$ of soil (fresh mass; water content 56%), equivalent to 150 kg $N \times ha^{-1}$.
AN: Ammonium nitrate, 3.4 $g \times kg^{-1}$ of soil, equivalent to 150 kg $N \times ha^{-1}$.

2.2.3. *Incubation*

The boxes were incubated in climate chambers in 12 + 12 h daily cycles of +20 and +15 °C (light off at night) for 40 weeks in the experiment with lime and ash, and for 28 weeks in the experiment with urea and ammonium nitrate. Winter conditions were simulated during the experiments by lowering the temperature by 5 °C each week, until it was close to zero under 24 h dark conditions. The winter conditions in both experiments were between weeks 16 and 23. Summer conditions were then re-established by reversing the procedure.

The boxes were covered with perforated plastic to reduce evaporation, and the soil was kept moist by watering at times with distilled water.

2.3. Sampling design and sample treatment

Samples were taken at the experimental sites at Tammela and Ruotsinkylä from 10 May to 19 September 1980, and from 10 June to 15 September 1981, respectively. At Tammela 5 permanent points were marked in each plod (10 on ash fertilized plots) on homogenous places. At each sampling one soil core was taken from each point. At Ruotsinkylä one soil core was taken from each treatment and block. Samples were taken at a minimum distance of 10 cm from previous samples with a cylindrical steel corer (area 9.4 cm^2) down to a depth of 6 cm. Before extraction, the soil samples were divided into 0 to 3 cm and 3 to 6 cm layers.

In the laboratory experiment with lime and ash, samples were taken 3, 8, 16, 30 and 40 weeks after the start, and in the experiment with urea and ammonium nitrate 0, 1, 3, 6, 9, 15and 28 weeks after the start. At each sampling 6 replicates of each of the test materials were removed from the boxes.

The samples from each layer in the field experiments, and the contents of each basket in the laboratory experiments were homogenized with a vibromixer in 500 ml of water for 1 min. At Tammela the nematodes were extracted from 100 ml subsamples with the decantation-filtration method of OOSTENBRINK (1960) modified by HUHTA & KOSKENNIEMI (1975). At Ruotsinkylä and in the laboratory experiments the extraction was made from 50 ml subsamples with the wet funnel method (SOHLENIUS, 1979). The nematodes were killed in hot water and stored in 4% formalin.

The nematodes from all units were counted under a binocular microscope at 50× magnification. For studying the feeding categories and different taxa, 5 blocks were pooled at Ruotsinkylä. 5 + 5 units from the field experiments and 3 + 3 units from the laboratory experiments were pooled into 2 subsamples. 300 random specimes were then identified from each pooled sample. The feeding categories were classified according to SOHLENIUS & SANDOR (1987).

Differences between the tratments were tested by the analysis of variance and, if significant differences were obtained, compared in pairs by the least significant difference (LSD) method.

3. Results

3.1. Effects of lime, ash and ash+phosphorus

3.1.1. *Field experiment at Ruotsinkylä (First year after the treatments)*

Ash+P

Ash+P treatment did not significantly affect the total number of nematodes (fig. 1). However two months after the treatment (July), the number of bacterial feeders was significantly higher in the treated plots than in the control plots. Among root/fungal feeders, *Tylencholaimus*, and among bacterial feeders, Cephalobidae showed increased numbers. Teratocephalida decreased initially but increased later on. The number of *Plectus* also decreased initially (table 2).

Table 2. Monthly mean numbers (10^{-4} m^{-2}) of different nematode taxa in the field experiment at Ruotsinkylä

	June	July	Aug.	Sept.	$\bar{x}$
Root/fungal feeders					
Tylenchus spp.					
Control	12	14[ab]	15	31	18[a]
Ash + P	9	26[a]	27	46	27[a]
Lime	10	12[bc]	17	20	15[a]
Urea	3	< 1[c]	9	22	9[b]
Ditylenchus spp.					
Control	14[a]	7	< 1	9[a]	8
Ash + P	8[ab]	3	1	9[a]	5
Lime	5[b]	2	3	10[a]	5
Urea	2[b]	4	3	3[b]	3
Aphelenchoides spp.					
Control	23	19	25	27	24
Ash + P	36	37	35	27	34
Lime	16	32	22	20	23
Urea	27	31	24	23	26
Tylencholaimus spp.					
Control	0[c]	9	10	6[ab]	6[a]
Ash + P	6[a]	4	5	8[b]	6[a]
Lime	5[ab]	8	9	11[a]	8[a]
Urea	2[bc]	5	7	2[b]	4[b]
Bacterial feeders					
Rhabditis spp.					
Control	38[b]	5[b]	9[bc]	7[b]	15[b]
Ash + P	9[b]	6[b]	< 1[c]	2[b]	4[b]
Lime	9[b]	16[b]	11[b]	27[b]	16[b]
Urea	178[a]	445[a]	126[a]	116[a]	216[a]
Bunonema spp.					
Control	< 1	< 1	< 1	< 1	< 1
Ash + P	< 1	< 1	< 1	< 1	< 1
Lime	< 1	< 1	< 1	< 1	< 1
Urea	< 1	< 1	< 1	< 1	< 1
Cephalobidae, *Gen. spp.*					
Control	52[b]	28	65[b]	62[b]	52[b]
Ash + P	60[ab]	46	95[ab]	80[b]	70[b]
Lime	25[b]	56	69[bc]	111[b]	65[b]
Urea	98[a]	123	115[a]	178[a]	129[a]
Teratocephalida, *Gen. spp.*					
Control	22	12[a]	5	11[b]	13
Ash + P	10	5[b]	19	42[a]	19
Lime	12	8[b]	3	10[b]	8
Urea	9	0[b]	17	2[c]	7
Plectus spp.					
Control	69[a]	30	53	101	63
Ash + P	50[b]	49	53	90	61
Lime	45[c]	44	49	91	57
Urea	28[d]	31	55	106	55
Wilsonema spp.					
Control	11	3	< 1	4	5
Ash + P	7	2	3	10	6
Lime	7	7	2	11	7
Urea	6	25	2	6	10

	June	July	Aug.	Sept.	x̄
Alaimus spp.					
Control	3[ab]	<1	2	3	2
Ash + P	2[ab]	2	13	0	4
Lime	3[a]	2	2	2	2
Urea	0[b]	2	2	0	1
Miscellaneous feeders					
Dorylaiminae, *Gen, spp.*					
Control	12	11[ab]	9	13	11
Ash + P	15	11[ab]	10	14	13
Lime	6	22[a]	12	21	15
Urea	3	<1[b]	7	9	5
Clarkus spp.					
Control	<1	<1	<1	5	2
Ash + P	<1	<1	<1	5	2
Lime	<1	<1	<1	6	2
Urea	<1	<1	<1	9	3

Note: Significant differences are indicated with different letters.

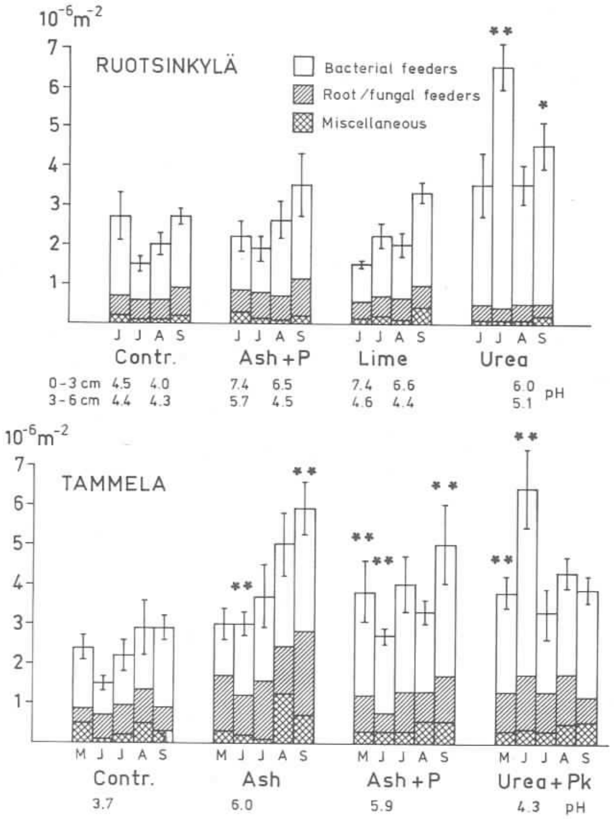

Fig. 1. Monthly total numbers of nematodes + SE, and proportions of different feeding groups in the field experiments (totals of 0–3 cm and 3–6 cm). Significant differences from the corresponding control samples indicated with asterisks. (* = P < 0.05, ** = P < 0.01). *p*H of humus shown under the graphs.

Lime

No significant differences in the mean number of nematodes for the sampling season were found between the limed plots and the control plots (fig. 1). One month after liming (June) the number of bacterial feeders was significantly lower in the limed plots than in the control plots. However, the number of the root/fungal feeders *Tylencholaimus* had increased initially (table 2). The number of the root/fungal feeders *Ditylenchus* and the number of the bacterial feeders Teratocephalida and *Plectus* decreased initially.

3.1.2. Field experiment at Tammela (Second year after the treatment)

Ash

By the second growing season, the ash treatment had significantly affected the nematode populations (fig. 1). The total number as well as those of root/fungal feeders and bacterial feeders was significantly higher in the treated plot than in the control plots (fig. 1).

Among root/fungal feeders, *Tylenchus* and *Aphelenchoides*, and among bacterial feeders Cephalobidae, *Plectus* and *Wilsonema* increased significantly, while the bacterial feeder *Bunonema* decreased significantly in the ash treated plot compared with the control plots (table 3). Dorylaiminae decreased in May and increased in August and September.

Ash+P

In the plot treated with ash+P the total number of nematodes as well as those of bacterial feeders was also significantly higher than in the control plots (fig. 1, table 3). The number of root/fungal feeders was also significantly higher in May and in September. The miscellaneous feeders showed decreased densities in May and increased densities in June, August and September.

The responses of different genera to treatment with ash+P were very similar to responses to ash alone with the exception of the *Bunonema* & *Wilsonema* (table 3).

3.1.3. Laboratory experiment

Both lime and ash resulted in a marked but transitory increase of bacterial feeding nematodes (fig. 2). However, in all but the first samples there were fewer nematodes in the treated soils than in the control. Since the bacterial feeders were dominant in the nematode community, the total number of nematodes was consequently reduced. The very abundant bacterial feeder *Wilsonema* in the control showed reduced numbers in both treatments. Among the bacterial feeders, Cephalobidae increased most rapidly in the treated soils, followed by *Rhabditis* (table 4). *Tylenchus*, Teratocephalida, *Monhystera* and *Alaimus* were suffered by the treatments. Decreased numbers were shown by several taxa from week 8 onwards. After 30 weeks all feeding categories were more abundant in the untreated soil than in the treated soils.

3.2. Effects of nitrogen fertilizers

3.2.1. Field experiment at Ruotsinkylä

Urea exerted a strong postive influence on the total population of nematodes. The difference between the urea treated and untreated plots was greatest in July (fig. 1). The increase was solely due to the bacterial feeders *Rhabditis* and Cephalobidae (table 2). *Tylenchus, Ditylenchus, Tylencholaimus,* Teratocephalida and Dorylaiminae decreased in comparison with the control plots.

3.2.2. Field experiment at Tammela

In the second year after the fertilization with urea+PK, the average total number was about twice as high as in the control plots. The difference was greatest in May and June (fig. 1). The increase was mainly caused by bacterial feeders, but in the 2 first samples root/fungal feeders were also significantly more abundant in the fertilized soil (table 3).

Table 3. Monthly mean numbers (10^{-4} m^{-2}) of different nematode taxa in the field experiment at Tammela.

	May	June	July	Aug.	Sept.	$\bar{x}$
Root/fungal feeders						
Tylenchus spp.						
Control	12^{c}	25^{bc}	29	41	34^{b}	28^{c}
Ash	60^{ab}	68^{b}	76	40	96^{a}	68^{a}
Ash + P	47^{b}	21^{c}	58	41	45^{b}	42^{b}
Urea + PK	66^{a}	100^{a}	25	74	50^{a}	63^{a}
Aphelenchoides spp.						
Control	15^{b}	24^{ab}	31	31	39^{b}	28^{c}
Ash	68^{a}	31^{a}	60	79	94^{a}	66^{a}
Ash + P	35^{b}	19^{b}	32	36	49^{b}	34^{b}
Urea + PK	29^{b}	32^{a}	56	36	20^{b}	35^{b}
Tylencholaimus spp.						
Control	5^{a}	2	0	2	3^{a}	2^{a}
Ash	1^{b}	2	4	0	2^{a}	2^{a}
Ash + P	0^{b}	3	1	0	$<1^{b}$	1^{b}
Urea + PK	0^{b}	3	<1	0	1^{b}	$<1^{b}$
Bacterial feeders						
Rhabditis spp.						
Control	9	7	6	2^{b}	6^{b}	6^{b}
Ash	8	5	10	8^{b}	7^{b}	8^{b}
Ash + P	1	13	6	7^{b}	12^{b}	8^{b}
Urea + PK	15	2	19	77^{a}	17^{a}	26^{a}
Bunonema spp.						
Control	*2*	3^{b}	*13*	*<1*	*4*	4^{a}
Ash	*<1*	$<1^{b}$	*1*	*<1*	*<1*	$<1^{b}$
Ash + P	*9*	11^{a}	*8*	*<1*	*8*	7^{a}
Urea + PK	*<1*	2^{b}	*<1*	*<1*	*<1*	$<1^{b}$
Cephalobidae, Gen. spp.						
Control	10	7^{c}	6	52	40^{b}	23^{b}
Ash	20	54^{ab}	98	66	77^{a}	63^{a}
Ash + P	36	23^{bc}	85	57	70^{a}	54^{a}
Urea + PK	26	89^{a}	30	70	53^{a}	54^{a}
Teratocephalida, *Gen. spp.*						
Control	49	21^{b}	37	15^{b}	60	36
Ash	30	52^{b}	44	34^{b}	90	50
Ash + P	50	20^{b}	50	80^{a}	75	55
Urea + PK	51	128^{a}	80	24^{b}	63	69
Plectus spp.						
Control	42^{b}	36^{c}	67	74	75^{b}	59^{b}
Ash	42^{b}	66^{b}	66	141	104^{ab}	84^{a}
Ash + P	146^{a}	130^{ab}	100	50	122^{a}	110^{a}
Urea + PK	132^{a}	220^{a}	60	70	103^{a}	117^{a}
Wilsonema spp.						
Control	6	2^{b}	2	2	4	3^{b}
Ash	10	9^{ab}	9	8	22	12^{a}
Ash + P	4	3^{b}	8	5	12	6^{b}
Urea + PK	26	23^{a}	12	6	14^{a}	16^{a}
Alaimus spp.						
Control	15	7	5^{b}	19	15	12
Ash	12	6	2^{b}	15	18	11
Ash + P	22	4	3^{b}	8	21	12
Urea + PK	7	10	10^{a}	11	19	11

	May	June	July	Aug.	Sept.	$\bar{x}$
Miscellaneous feeders						
Dorylaiminae, *Gen. spp.*						
Control	63^a	10^b	19	49^b	25^b	33
Ash	22^b	11^b	12	116^a	48^a	42
Ash + P	27^b	25^a	24	59^a	61^a	39
Urea + PK	37^b	30^a	30	49^b	40^a	37
Clarkus spp.						
Control	<1	<1	<1	<1	<1	<1
Ash	<1	<1	<1	<1	<1	<1
Ash + P	<1	<1	<1	<1	<1	<1
Urea + PK	<1	<1	<1	<1	<1	<1

Note: Significant differences are indicated with different letters.

Of the rood/fungal feeders, *Tylenchus* and *Aphelenchoides* and of the bacterial feeders, *Rhabditis,* Cephalobidae, *Plectus* and *Wilsonema* increased after nitrogen fertilization. Teratocephalida and *Alaimus* also showed increased numbers in some samples. Of the root/fungal feeders, *Tylencholaimus,* and of the bacterial feeders, *Bunonema* showed decreased numbers in some samples. Dorylaiminae had decreased in May but increased later on (table 3).

3. 2. 3. Laboratory experiment

In the urea treated soil the total number of nematodes as well as those of bacterial feeders exceeded the control level only during the first few weeks (fig. 3). The increase was due to the bacterial feeders *Rhabditis* and Cephalobidae (table 5). These were also more numerous in the treated soil 9 weeks after the start, when the total number of bacterial feeders was lower than in the control soil. The number of root/fungal feeders and miscellaneous feeders dropped under the control level after a few weeks and *Tylenchus, Wilsonema* and *Alaimus* had decreased in numbers (fig. 3, table 5).

In the soil treated with ammonium nitrate, all feeding categories of nematodes were significantly less numerous than in the control soil (fig. 3 and table 5). However, the number of the root/fungal feeder *Tylencholaimus* increased 15 weeks after the start. *Tylenchus,* Cephalobidae, *Alaimus* and Dorylaiminae decreased initially.

4. Discussion

4.1. Effects of lime and ash on feeding categories

Franz (1959) reported an increase of nematodes immediately after liming, and after two years the abundance of nematodes had reached the control level. Bassus (1960) also observed higher nematode numbers after liming with the response persisting for 6 years after treatment. No initial effect was found after the application of $Ca(OH)_2$ in our field experiment. One explantation could be that the doses of lime applied by Franz (1959) and Bassus (1960) were much higher than in our study.

The results of our laboratory experiment were rather similar to those obtained by Heungens (1981). He studied the effects of KOH and $Ca(OH)_2$ on nematodes in pine litter in different temperatures. After 2, 4 and 6 months the number of saprophagous nematodes in the treated pine litter was higher than in untreated pine litter. The temperature was 6 °C for the first 2 months, 9 °C for the next 2 months and 15 °C for the last two.

In our laboratory experiment the initial effect of lime on the number of nematodes was observed earlier than in the study by Heungens (1981). The initial temperatures in our experiment were higher (15–20 °C) than those used by Heungens (1981), which may explain the differences. The positive effect of lime observed by Heungens (1981) was of longer duration (6 months) than in our

Table 4. Mean numbers of different taxa per sample unit in the laboratory experiment with ash+P and lime.

Weeks	3	8	16	30	40
Root/fungal feeders					
Tylenchus spp.					
Control	423	1,309^{a}	243	275	222
Ash+P	408	304^{b}	414	178	286
Lime	161	603^{b}	155	184	121
Ditylenchus spp.					
Control	31	68	73^{a}	35	0
Ash+P	55	0	64^{ab}	17	18
Lime	0	114	34^{b}	3	23
Aphelenchoides spp.					
Control	640	68	11	9	72
Ash+P	1,152	219	19	43	46
Lime	796	54	17	42	41
Tylencholaimus spp.					
Control	0	0	13	35	6
Ash+P	0	0	0	17	0
Lime	0	0	23	3	9
Bacterial feeders					
Rhabditis spp.					
Control	62	117^{b}	0^{b}	26	38
Ash+P	1,395	1,983^{a}	204^{ab}	125	69
Lime	515	1,273^{a}	333^{a}	97	45
Cephalobidae, Gen. sp.					
Control	3,381^{b}	1,554	297	680	369^{a}
Ash+P	8,298a	1,326	339	374	153^{b}
Lime	7,744^{a}	2,026	137	170	118^{b}
Teratocephalida, Gen. spp.					
Control	140	142	48^{a}	23	10^{b}
Ash+P	110	61	6^{b}	50	10^{b}
Lime	56	0	0^{b}	10	36^{a}
Plectus spp.					
Control	335	703	417	260^{a}	129
Ash+P	1,163	384	402	95^{b}	34
Lime	949	742	195	81^{b}	79
Wilsonema spp.					
Control	202	2,212^{a}	391^{a}	85	4
Ash+P	0	69^{b}	0^{b}	0	7
Lime	152	211^{b}	28^{b}	3	5
Monhystera spp.					
Control	171	352^{a}	269^{a}	112^{a}	114
Ash+P	129	89^{b}	0^{b}	25^{b}	14
Lime	0	78^{b}	11^{b}	11^{b}	17
Alaimus spp.					
Control	0	177	288^{a}	171^{a}	12
Ash+P	0	56	37^{b}	11^{b}	3
Lime	0	60	11^{b}	3^{b}	3
Miscellaneous feeders					
Dorylaiminae Gen. spp.					
Control	93	322	173	352^{a}	80
Ash+P	165	154	431	131^{b}	56
Lime	56	114	190	131^{b}	34
Clarkus spp.					
Control	<1	<1	<1	<1	<1
Ash+P	<1	<1	<1	<1	<1
Lime	<1	<1	<1	<1	<1

Note: Significant differences are indicated with different letters.

Table 5. Mean numbers of different taxa per sample unit in the laboratory experiment with urea and ammonium nitrate.

Weeks	0	1	3	6	9	15	28
Root/fungal feeders							
Tylenchus spp.							
Control	294	22	45^{a}	116	243^{a}	351^{a}	30
Urea	409	63	0^{b}	29	19^{b}	87^{b}	25
Ammonium nitrate	252	27	12^{b}	12	34^{b}	81^{b}	22
Ditylenchus spp.							
Control	6^{b}	24	16^{a}	0	0	11	0
Urea	59^{a}	10	0^{b}	0	0	14	0
Ammonium nitrate	9^{b}	25	25^{a}	0	0	5	0
Aphelenchoides spp.							
Control	174	27	127	227	133	55	4
Urea	229	37	83	104	70	5	9
Ammonium nitrate	239	75	103	314	61	21	16
Tylencholaimus spp.							
Control	41	14	19	50	13	0^{b}	0
Urea	48	0	0	29	26	9^{ab}	0
Ammonium nitrate	39	11	3	18	5	19^{a}	2
Bacterial feeders							
Rhabditis spp.							
Control	17	2^{b}	32	38	13^{b}	44	0
Urea	6	66^{a}	259	85	134^{a}	101	48
Ammonium nitrate	17	2^{a}	9	46	13^{b}	0	2
Cephalobidae, Gen. spp.							
Control	157	140^{a}	1,064	1,738	797^{b}	482	148
Urea	233	352^{a}	2,364	1,078	$1{,}096^{a}$	371	230
Ammonium nitrate	138	44^{b}	81	416	783^{b}	623	311
Teratocephalida, Gen. spp.							
Control	215	18	16	25	27	10	22
Urea	154	10	20	31	9	4	2
Ammonium nitrate	39	0	0	10	0	5	9
Plectus spp.							
Control	348	120	101	319	364^{a}	197^{a}	64
Urea	321	112	179	231	195^{b}	103^{b}	46
Ammonium nitrate	271	64	59	43	22^{c}	178^{a}	39
Wilsonema spp.							
Control	81	45	87	1,130	700^{a}	790^{a}	368
Urea	46	10	83	191	127^{b}	88^{c}	35
Ammonium nitrate	15	11	6	122	117^{b}	323b	178
Monhystera spp.							
Control	8	7	0	0	151	22	0
Urea	91	0	0	0	9	5	0
Ammonium nitrate	46	11	6	18	0	5	0
Alaimus spp.							
Control	72^{a}	18	49	26	54	77^{a}	89
Urea	11^{b}	0	82	8	16	0^{b}	27
Ammonium nitrate	4^{b}	3	3	5	11	0^{b}	15
Miscellaneous feeders							
Dorylaiminae, Gen. spp.							
Control	70^{ab}	74^{a}	123^{a}	178^{a}	160	163	135
Urea	149^{a}	58^{a}	52^{ab}	95^{b}	107	162	156
Ammonium nitrate	21^{b}	0^{b}	0^{b}	10^{c}	44	76	65

Note: Significant differences are indicated with different letters.

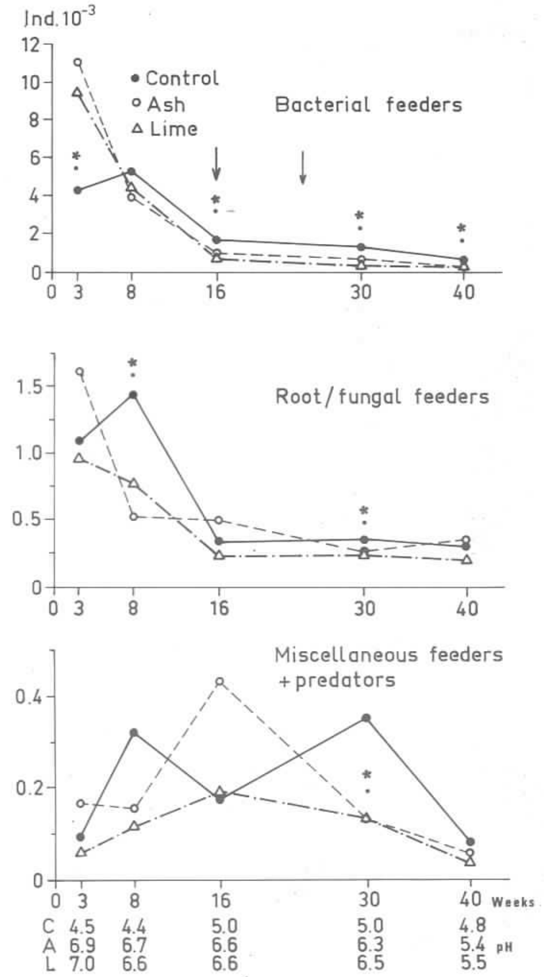

Fig. 2. Numbers of different feeding groups of nematodes per sample unit in the laboratory experiment with ash and lime. Significant differences between A and C are indicated with askerisks and those between L and C with dots. (* = $P < 0.05$, ** = $P < 0.01$). *p*H of humus shown under the graphs. The vertical arrows indicate start and end of winter conditions.

study (a few weeks). However, pine litter might be better than humus as a substrate for microorganisms.

However, only the number of *Rhabditis* and Cephalobidae initially showed a positive correlation with the soil *p*H, while that of other bacterial feeders remained unchanged or decreased. The *Rhabditis* species are fairly uncommon in the coniferous forest soil, while Cephalobidae, particularly *Acrobeloides nanus,* are among the dominant bacterial feeders. Both genera probably live under conditions of limited food supply (SOHLENIUS, 1973a, b). SOHLENIUS (1973b) and BÅÅTH *et al.* (1978) assumed that the population development of the *Rhabditis* species occurs in connection with high bacterial activity.

BASSUS (1960, 1967) and HEUNGENS (1981) also assumed that the number of nematodes correlates positively with soil *p*H, because liming results in an increase of bacteria, i.e., the food supply for bacterial feeding nematodes. HEUNGENS (1981) could, however, not exlude a positive effect of increased *p*H on hatching of nematode eggs.

Liming has been shown to increase soil respiration (CZERNEY & MAI, 1970; IVARSON, 1977;

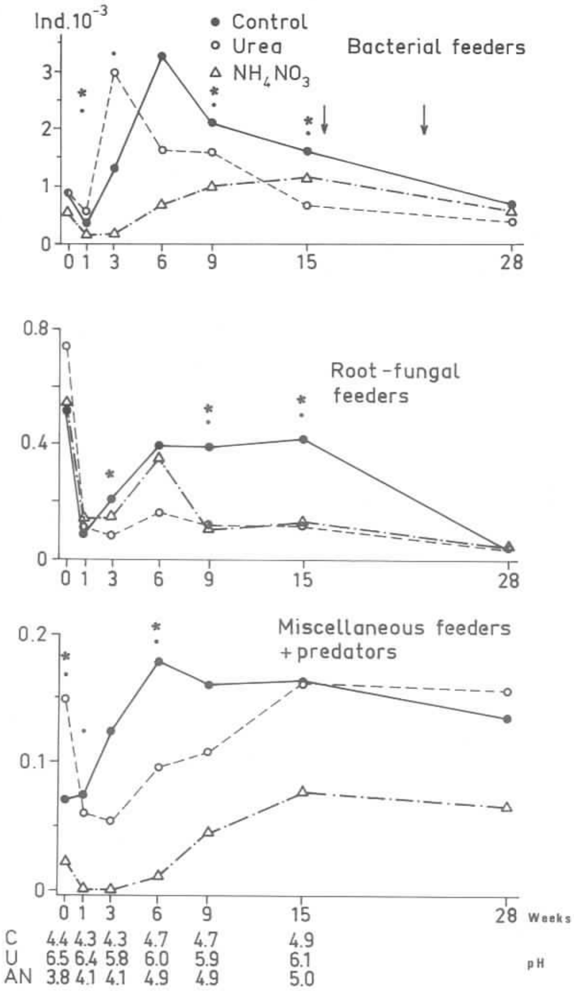

Fig. 3. Numbers of different feeding groups of nematodes per sample unit in the laboratory experiment with urea and ammonium nitrate. Significant differences between U and C are indicated with asterisks and those between A N and C with dots. ($* = P < 0.05$, $** = P < 0.01$). *p*H of humus shown under the graphs.

MAI & FIEDLER, 1978), which indicates higher microbial activity. Bacteria have been observed to increase in numbers after application of lime in several plate count studies (FIEDLER & HUNGER, 1963; CZERNEY & MAI, 1970; IVARSON, 1977; ADAMS *et al.*, 1978; MAI & FIEDLER, 1978). However, BÅÅTH *et al.* (1980), using the direct count method, found no significant differences in bacterial numbers and biomass between limed and untreated plots.

SÖDERSTRÖM (1984) supposed that liming stimulates only the active and culturable bacteria without any total increase in bacterial numbers and biomass. Thus, it is possible that these bacteria are suitable food for *Rhabditis* and Cephalobidae, while the other bacterial feeders are adapted to other bacteria. Another explanation for the reaction of bacterial feeding nematodes could be that the *Rhabditis* and Cephalobidae species are more able to compete for resources than the other bacterial feeders. This might also explain the increase of *Plectus spp.* species at Tammela, where no flush of *Rhabditis* and Cephalobidae was observed.

Thus, the effects of lime and ash were very similar on the bacterial feeding nematodes. The changes in the numbers of *Rhabditis* and Cephalobidae are probably related to the *p*H effects on

active bacteria. However, the results of the field experiments were rather different from those of the laboratory experiment. One explanation could be that the temperature and moisture conditions for these species were more favorable in the laboratory experiment. The slower solubility of ash and lime in the field is also an important factor which could account for the differences.

Bassus (1960) also observed an increase of *Tylenchus* after liming and suggested that this was because the amount of fungal hyphae was reduced by liming but fine root biomass increased.

Ivarson (1977) found a negative initial effect of liming on fungal hyphae, and the same response on FDA-active hyphae was observed by Persson *et al.* (in prep.). Liming (and ash) treatment seemed to cause better rooting in humus layer, but have a negative initial effect on the production of fine roots in mineral soil. This negative effect disappeared after some time (H. Persson unpubl.).

There were more *Tylenchus spp.* in the ash+P treatments in both field experiments, but in the laboratory experiment the numbers of *Tylenchus* had decreased. The amount of living roots was probably negligible in the laboratory experiment. However, the differences and similarities between the effects of lime and ash on the root/fungal feeders are more difficult to explain than those of lime and ash on bacterial feeders.

4.2. Effects of nitrogen fertilizers on feeding categories

Marshall (1974) found increased numbers of nematodes one month after the application of 448 kg urea × ha^{-1} in a thinned Douglas fir stand. A similar increase of the total number of nematodes after urea treatment was found in our field experiments, where the highest numbers were found when the densities were lowest in the control plots.

Urea increases the soil *p*H (Schalin, 1967; Persson, 1984). A rise in the *p*H makes carbon compounds more available for the microorganisms (Salonius, 1972), and urea also results in increased bacterial numbers (Schalin, 1967; Salonius, 1972; Roberge, 1976; Kelly & Henderson, 1978). Thus, it is possible that the higher number of the bacterial feeders *Rhabditis* and Cephalobidae after the urea treatment was due increase of bacteria. However, in the field experiment at Ruotsinkylä it was difficult to distinguish between the effect of *p*H and that of death of mosses on the food supply.

The effect of urea was not as evident in the laboratory experiment as in the field experiment. The absence of roots in the laboratory experiment might be an important factor in explaining the difference. The high nitrogen content in the laboratory study may also have counteracted the positive *p*H effect of urea.

The application of ammonium nitrate reduced the nematode numbers, and the initial negative effect was more marked on bacterial feeders than on root/fungal feeders. Sohlenius & Wasilewska (1984) observed reduced numbers of nematodes after repeated addition of ammonium nitrate in a pine forest soil. Bååth *et al.* (1978) found increased numbers of the bacterial feeders *Rhabditis* and *Diplogaster* in soils supplied with ammonium nitrate.

One important difference between the study by Bååth *et al.* (1978) and our laboratory experiment was the substrate for experimental systems. The material used by Bååth *et al.* (1978) was a mixture of humus, sand and perlite, to which dolomite lime was added. As a result, the *p*H in the soil amended with ammonium nitrate was also higher in their experiment than in ours. In addition, living pine seedlings were present in their study.

Altough it is difficult to conclude whether the reaction of nematodes in our laboratory experiment was due to the *p*H or nitrogen effect; our laboratory experiment showed that ammonium nitrate reduced the number of bacterial feeders. The number of root/fungal feeders was initially unchanged in both nitrogen treatments, but after 3 weeks a tendency of reduced numbers was observed.

4.3. Sensitivity to fertilizers

Indirect effects of fertilizers due to changes in food supply were discussed above. However, the decrease of dorylaimids is in agreement with the observations on sensitivity by Ferris & Ferris (1974), Wasilewska (1979) and Sohlenius & Wasilewska (1984). It is possible that the decline

in the numbers of Teratocephalida, *Wilsonema, Monhystera* and *Alaimus* could also be explained with sensitivity to fertilizers. Dorylaimida, *Wilsonema, Monhystera* and *Alaimus* belongs to Adenophora, which seems to be more sensitive than Secernentea to application of certain chemicals (HYVÖNEN in prep.).

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Synopsis: *Original scientific paper*

HYVÖNEN, R., & V. HUHTA, 1989. Effects of lime, ash and nitrogen fertilizers on nematodes populations in Scots pine forests soils. Pedobiologia **33**, 129–143.

Response of nematode populations to manipulation of *p*H and nutrient status with fertilization was studied in field and laboratory conditions. To separate the role of acidity from that of nutrients, ash treatments were controlled with $Ca(OH)_2$, and urea with NH_4NO_3. Urea, ash and lime all caused an increase of bacterial feeding *Rhabditis* and Cephalobidae. In the laboratory the response was more rapid but remained transitory, while in the field the effect of ash did become evident in the second growing season. The response after lime and ash treatment can be explained merely by the rise of *p*H, while the pattern after nitrogen fertilizers seems to be more complicated. Dorylaimid and several other adenophorean nematodes are supposed to be sensitive to fertilizers.

Key words: Nematoda, fertilization, liming, nitrogen, urea, *p*H, forest soil, raw humus.

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